CENTRAL FORECASTING TECHNICAL NOTE NO.4

TRIAL OF THE IMPACT OF BOGUS DATA IN THE FINE-MESH MODEL

J.T.HEMING

December 1990

Central Forecasting Division
Meteorological Office
London Road
Bracknell Berkshire
RG12 2SZ

N.B. This paper has not been published. Permission to quote from it should be obtained from the Assistant Director of the above Meteorological Office Division.

Introduction

It is the task of the Intervention Bench of the Central Forecasting Office (CFO) to continually monitor data received at Bracknell and to correct or reject observations, as deemed necessary, before each run of the global and fine-mesh models. The facility also exists to create "bogus" observations for use in data sparse areas or as support for existing observations. It is possible to create bogus mean sea-level pressure, wind speed and direction, relative humidity, 500-1000mb thickness and height records throughout the depth of the model atmosphere. Such manual action is known as Intervention.

An assessment of the overall effect of CFO intervention on the operational NWP models is required for the purposes of evaluating the CFO effort and identifying recurring problems. In the past the impact of bogus data has been assessed by individual case studies chosen because bogus data was known to have a particularly good or bad effect on the operational forecast. However, an unbiased assessment can only be made by selecting a number of cases at random and examining the impact of bogus data in each.

CFO's attention is focused on the global model and ideally a full assessment should be made of global intervention. However, in an attempt to obtain some results using the resources available during the first half of 1990, a trial was carried out on the fine-mesh model. The effects of bogus data only were investigated; CFO rejections and corrections, of which there are very few at the time of the fine-mesh cut-off, applied to both the Control (operational) and Trial (no bogus) runs. On average CFO supply only about one tenth of the number of bogus data for fine-mesh runs as are supplied for the global update runs. However, these data are likely to have greatest impact in the area around the UK which is of greatest importance to the Office's national operations.

The fine-mesh model operates with a 4-cycle assimilation, producing 36-hour forecasts every six hours as follows:-

	0000/1200 GMT	Global analysis interpolated onto the fine-mesh grid
Cycle 1	0300/1500 GMT	Assimilation
	0600/1800 GMT	Intermediate assimilation and 36-hour forecast
Cycle 2	0600/1800 GMT	Update assimilation including data received after the intermediate assimilation
Cycle 3	0900/2100 GMT	Assimilation
Cycle 4	1200/0000 GMT	Assimilation and 36-hour forecast

The bogus effort is concentrated on the 0000, 0600, 1200 and 1800 GMT runs of the fine-mesh model since these data may also be used in the corresponding global model runs to follow. Less frequently, bogus data are inserted into the 0300, 0900, 1500 and 2100 GMT runs of the fine-mesh model.

Preparatory Work for the Trial

In an attempt to select a representative sample of cases from around the year, it was decided to examine 25 cases from July 1989, just after the Analysis Correction Scheme became operational in the fine-mesh, to April 1990, excluding the period in August and September 1989 when the model reverted to the previous assimilation scheme during the Cyber upgrade. A single case comprised a 4-cycle assimilation culminating at 0000/1200 GMT followed by a 36-hour forecast. Over the 10 month sample period there were 549 such 4-cycle assimilations from which to select the 25 cases.

Since many fine-mesh runs have very few bogus data, or none at all, it would be wasteful to select the 25 trial cases entirely at random. Hence the cases were stratified into three groups determined by the total number of bogus data supplied over the 4-cycle assimilation. These groups were nil or trivial bogus (0-5), intermediate bogus (6-19) and substantial bogus (20 or more). For this trial it was decided to select the 25 cases from those with substantial bogus of which there were 124 over the sample period. It was also decided to select a larger proportion of cases from January and February since there were many more cases of substantial bogus than at other times as a result of increased intervention during the exceptionally stormy period. From the total of 25 cases 12 were selected at random from the period July-December 1989, 9 from January-February 1990 and 4 from March-April 1990.

Once the cases had been selected, each 4-cycle assimilation was rerun with and without the inclusion of bogus data using operational data from the DTT archives. If the first cycle of the Control assimilation (0300/1500 GMT) included no bogus data, as was the case on 24 of the 25 occasions, then both the Control and Trial reruns were started with the 0600/1800 GMT cycle of the assimilation.

Fine-mesh printfiles of background and analysis fields were created for each cycle including fields of likely interest. A more extensive forecast printfile was also created for each case. After each rerun was completed a number of analysis and forecast charts were produced including mean sea-level pressure, rainfall rate and accumulation, 500-1000mb thickness and 500mb height. In addition, further charts were produced depending on the nature of the bogus data supplied; e.g. if significant bogus upper-air wind data were inserted, analysis and forecast charts of maximum wind were produced. As well as assessing the impact of bogus data subjectively by chart comparison, it was intended to make an objective assessment by use of the verification package. Unfortunately, it was not possible to use the verification programs on most of the fields produced by each case. However, it was possible to verify forecast rainfall values against observations and produce a variety of verification statistics to assess the impact of bogus data on this aspect of the model's performance.

Case Studies

The charts and rainfall statistics produced by both the Control and Trial runs for each case were compared for any noticeable differences. In many of the 25 cases differences in analysis fields were noted as a direct result of the inclusion of bogus data. However, of greatest importance to this study is the impact of bogus data on the model forecast and whether its omission would have prompted the forecaster on the bench, who uses the model

products as guidance, to issue a forecast which differed from that issued operationally. Of the 25 cases it was considered that only 7 showed large enough forecast differences to fall into this category. These cases were verified against observations and model analyses.

CASE 1 Forecast from DT 1200 GMT 17.08.89

The whole of the UK was under the influence of a broad westerly airflow at the analysis time of 1200 GMT 17th August. An area of high pressure extended across France and much of Western Europe. A complex area of low pressure to the north and west of the UK comprised distinct centres directly north of Scotland and to the east of Greenland and further minor centres on a trough extending south-west towards Newfoundland. During the forecast period, the depression to the east of Greenland deepened and moved towards the north of the UK, but its movement was arrested by the anticyclone over France which intensified and moved north over the southern half of the UK.

A total of 40 bogus observations were inserted at 0600, 0900 and 1200 GMT. All were in the vicinity of the deepening depression to the east of Greenland and all but three were mean sea-level pressure (MSLP) observations with increments of -2mb to -4mb - many also with surface wind supplied. The other three observations were AIREP support near the jet core situated above this depression; increments of 35 to 50 knots were supplied. The bogus data were well structured and intended to deepen the depression and position it slightly further south.

The 1200 GMT analysis showed differences of up to 5 knots in the maximum wind speed between the Control and Trial runs to the north-east of the jet core in the region of the bogus data. The differences in the analysed MSLP fields were small, but significant. The Control analysis deepened the depression to the east of Greenland by 1mb and positioned it slightly further south when compared with the Trial analysis which developed the trough to the south-west of the main depression and produced a low centre some 8 degrees south of the main depression.

During the forecast, the differences in the maximum wind speed fields reduced to just 2 knots by T+24. However, the differences in MSLP amplify in the forecast. As Fig.1(a) shows, the Control forecast developed the main depression and moved it towards Scotland by T+24 with a central pressure of 995mb. In contrast, the Trial forecast (Fig.1(b)) featured no distinct centre in the same region, but developed a low centre on the trough to the south-west with a central pressure of 1003mb. The verifying analysis (Fig.1(c)) shows a single centre of 990mb positioned 2-3 degrees south-west of the Control centre and 6-7 degrees north-north-east of the Trial centre. Although neither forecast was totally correct, the Control was closer since it developed the main depression and not the trough and had a centre closer to the verifying analysis in terms of position and central pressure. The forecast surface wind speed to the east of the main depression was stronger in the Control run due to its extra isobar and tighter gradient. Although there were no observations against which to verify the winds in this area, the verifying analysis suggests that the Control forecast is the better of the two in this respect.

Despite the MSLP field differences, the forecast rainfall patterns for the two runs were very similar. There was only a small amount of additional rain forecast by the Control run to the west of the main

depression centre and a small additional amount in the region of the trough centre in the Trial run. In any case, the rain was only just approaching the northern and western coasts of Scotland and Ireland by T+36, so verification would be impossible since all the rain forecast throughout the previous 36 hours was over sea areas.

CASE 2 Forecast from DT 1200 GMT 11.12.89

A deep depression was positioned to the south of Greenland at 1200 GMT 11th December with a central pressure of 954mb. An associated trough and frontal system extended east towards the UK. A shallow secondary depression was developing directly to the south of the main depression. During the early part of the forecast period the main frontal system crossed the UK. Later in the forecast the developing secondary depression approached the south-west of Ireland and England with an associated frontal system.

A total of 21 bogus observations were inserted into the 0600, 0900 and 1200 GMT assimilation cycles, most of which were MSLP and surface wind at 0600 GMT. These were intended to strengthen the main depression and weaken the secondary depression. At 0900 GMT a few MSLP bogus observations were inserted to perform minor isobaric reshaping in the Biscay area. At 1200 GMT a number of 500-1000mb thickness (hereafter simply referred to as thickness) and 250mb height observations were inserted to strengthen the trough associated with the main frontal system.

The 0600 GMT analysis shows that the bogus had the desired effect of strengthening the main depression (by 4mb) and weakening the secondary depression (by 1mb) although the bogus increments implied much larger changes (13mb and 7mb respectively). By 1200 GMT the main depression was just 2mb deeper in the Control analysis although there was increased troughing along the frontal zone. At this stage the secondary depression was a shallow elongated feature with two centres. The Control analysis at 1200 GMT tended to develop the western centre of the complex whereas the Trial analysis deepened the eastern centre at the expense of the western centre.

The bogus also produced an increase in jet core wind speed of 5 knots in the region of the main depression in the 1200 GMT analysis. The Control forecast maintained the increased jet core speed and at T+24 was 102 knots - some 4 knots higher than the Trial forecast. The strongest observed wind speed in the area was 100 knots, but the verifying analysis showed a maximum of 97 knots, so if either could be said to have a better maximum wind speed field, it is the Trial forecast.

The accentuated troughing along the main frontal zone was maintained in the Control forecast, but had little impact on the rainfall pattern as it crossed the country from T+6 to T+24. During the later part of the forecast (T+24 to T+36) both the Control and Trial runs pushed the secondary depression towards the UK too quickly. However, the Control forecast kept the depression slightly further west when compared with the Trial run (Figs.2(a) and 2(b)). This resulted in a slight difference in the timing of the onset of rain in southern and western parts of England and particularly Ireland. Although the Control forecast was slightly better than the Trial, it was poor when considered against observations which show rain only just reaching south-west England and Wales at 0300 GMT - some three hours after the forecast verifying time (see Figs.2(c) and 2(d)).

CASE 3 Forecast from DT 1200 GMT 24.12.89

At the analysis time of 1200 GMT 24th December the whole of the UK was under a strong south-westerly airstream produced by an intense depression to the south-west of Iceland with a central pressure of 929mb. During the forecast period a frontal system crossed the country and the depression centre moved slowly eastwards.

A total of 36 bogus observations were used in the 0600 and 1200 GMT assimilation cycles. At 0600 GMT MSLP and surface wind bogus were inserted to support Atlantic ships. An attempt was also made to reposition the 546dam thickness contour further west in the region of the frontal zone. At 1200 GMT there was further ship support, but mainly relative humidity bogus along the front at the 850, 700 and 500mb levels, with the intention of moistening it considerably. Values 85 or 90% were inserted which represents increments mostly between 30% and 70%.

The analysis differences between the Control and the Trial runs were fairly modest. There was minor isobaric reshaping and relative humidity differences of up to 20%. In the forecast, the differences were still small, but significant in terms of the frontal clearance. Figs.3(a) and 3(b) show the T+12 forecasts of MSLP and rainfall rate for the Control and Trial runs respectively. They show that the front was moistened and held back slightly as a result of the thickness and relative humidity bogus. The Control run forecast rain over the south-east corner of the country whereas the rain had just cleared into the North Sea in the Trial run. This represents a timing difference in frontal clearance of 2-3 hours. Fig.3(c) shows the verifying observations at 0000 GMT 25th and indicates light rain in the far south and east of the country with rain having cleared within the past hour further inland. By 0300 GMT (Fig.3(d)) the front had moved into the North Sea. Behind it, East Anglia and parts of south-east England experienced occasional light rain. The observed rainfall pattern fell somewhere between the two forecasts, but it was concluded that the Control run was the better forecast since some rain was experienced in the South-East between 0000 and 0300 GMT; hence the bogus had a small positive impact. As the front continued its movement eastwards, the rain associated with it died out in both the Control and Trial forecasts.

CASE 4 Forecast from DT 0000 GMT 06.02.90

At 1800 GMT 5th February the UK was under a strong south-westerly airstream which was part of the circulation of a low pressure complex situated over and to the north-east of Iceland. A secondary depression was developing in the western half of the North Atlantic, but of greatest interest to this case was a wave developing to the north-west of the Iberian peninsula just ahead of a confluent upper trough. By 0000 GMT this feature had progressed towards south-west Ireland and during the forecast period crossed Ireland and Scotland bringing much rain.

Bogus observations were inserted at a total of 60 different positions, the vast majority of which were at 1800 GMT in the vicinity of the wave off the Iberian peninsula. These included MSLP and surface wind, thickness bogus to contort the thermal pattern and 700mb relative humidity observations of 80-90% to moisten the feature. There were also a number of bogus supporting AIREP observations inserted further west near the secondary

depression in an attempt to increase the jet strength. A single MSLP bogus observation was inserted at 2100 GMT and at 0000 GMT 8 observations of MSLP, thickness and 700mb relative humidity were inserted in the region of the wave.

The response of the 1800 GMT analysis fields to the large amount of bogus data was varied. The MSLP field showed more troughing near the wave, but it was intended that the bogus data should produce a distinct centre some 4mb deeper than the actual analysis. The thickness bogus was inserted to strengthen the thermal trough in the region of the 500mb trough and considerably amplify the thermal ridge further north-east near the wave. A certain degree of success was attained in the 1800 GMT analysis, but the increments of up to 14dam supplied produced a change in the analysis of 4dam at most. The 700mb relative humidity analysis shows a good response to the bogus with a region of greater than 95% relative humidity extended south towards the Iberian Peninsula. Differences between the Control and Trial analyses were up to 40%; increments supplied were up to 60%. Further west AIREP support with increments of up to 46 knots were supplied. The result was a jet core 6 knots stronger and local differences of up to 12 knots between the Control and Trial analyses.

At 0000 GMT the MSLP analyses showed very small differences as a result of the bogus data; the wave had a labelled centre in the Control run and not the Trial run, but isobarically they showed minor differences. The Control thickness analysis had lost much of the bogus impact by 0000 GMT and differences of 2 dam at most were present between the two runs. The 700mb relative humidity field maintained the bogus impact in the 0000 GMT analysis and extended the area of relative humidity greater than 95% further south in the Control analysis. By 0000 GMT, the impact of bogus data on the analysis of the jet core speed in mid-Atlantic had been totally lost. In the vicinity of the core differences of up to 10 knots were present between the two analyses.

The impact of AIREP support continued to be lost in the forecast; by T+24 differences of just 3-4 knots could be noted between the Control and Trial runs. However, the bogus related to the wave made a significat difference as it crossed the UK. As Fig.4(a) shows, the Control T+18 forecast positioned the wave over Northern Ireland and forecast much rain, both dynamic and convective, over Ireland and across Scotland. The Trial forecast (Fig.4(b)) confined the light rain and showers to south-east Ireland and parts of Scotland. At T+24 the situation was similar; the Control run forecast considerably larger rainfall totals over Scotland. The differences in MSLP between the two forecasts were, in fact, very small; the Control forecast just featured a closed isobar at T+18. Similarly, the amplification of the thermal ridge bogussed at 1800 GMT was only just detectable in the forecast. However, the 700mb relative humidity field still showed some significant differences by T+18 in the Control run increasing the relative humidity by over 30% in the important areas where the rainfall differences occured. Figs.4(c) to 4(e) show the verifying analysis for 1800 GMT and observations for 1500 and 1800 GMT. These indicate that the wave was a deeper feature than predicted by either forecast and hence produced considerably more rain than even the Control forecast. As the verifying charts show, the wave also progressed north-eastwards more rapidly than forecast and most of the rain had cleared Ireland and moved into Scotland by 1800 GMT.

This is clearly a case of bogus data improving the forecast, but considering the amount of bogus data supplied, the results were disappointing. The MSLP and thickness analysis differences leading to forecast differences, in particular, were small. A closer inspection of the MSLP bogus data at 1800 GMT show that some 31 observations were inserted in an area of 10x20 degrees, some of which were ship support and some intended to create a distinct circulation on the wave. Near the wave's centre the bogus data indicate some very small scale contortions in the isobaric pattern and pressure gradients of up to 4mb within one fine-mesh grid-point. This is clearly beyond the model's resolution and the fine-mesh analysis did not produce the desired circulation, which influenced the success of the subsequent forecast. However, the relative humidity bogus data, just 7 observations in all, maintained their impact throughout the forecast and undoubtedly influenced the rainfall forecast in the critical area through Ireland and Scotland.

CASE 5 Forecast from DT 0000 GMT 08.02.90

At 1800 GMT 7th February a mature depression was situated over Iceland. Within its circulation a vigorous secondary depression had formed and was positioned over Ireland producing extremely windy conditions across much of England and Wales. Further to the west there were two troughs in the isobaric pattern; a minor one at 45N 32W and a sharper feature at 45N 47W. By 0000 GMT the depression over Ireland had moved across the UK into the North Sea and the two troughs had started to make progress eastwards. The forecast and impact of bogus data on it was concentrated on these two troughs as they approached the UK.

A total of 39 bogus observations were used in the 1800, 2100 and 0000 GMT cycles of the assimilation. 20 of these were MSLP and surface wind observations at 1800 GMT. Most of these were in the region of the depression over Ireland with the intention of deepening it. The remainder were inserted around the easternmost of the two troughs (the minor feature) also with the intention of deepening it. The bogus observations at 2100 and 0000 GMT were all MSLP, mostly with surface wind, inserted around the depression crossing the UK and the parent depression over Iceland. There was also some ship support in the Atlantic and noticeably a single thickness bogus observation inserted just to the north of the easternmost trough with a positive increment.

At 1800 GMT 7th February the Control analysis showed small differences from the Trial run in the region of the bogus data. The depression over Ireland was 1mb deeper and the easternmost trough had been opened up and given a distinct centre of 1007mb; increments of up to 3mb were supplied. The thickness pattern around the trough was almost identical for the two runs at this stage. By 0000 GMT the effect of the bogus had been all but lost in the MSLP field. The Control analysis depression over Iceland was 1mb deeper, but the isobaric pattern around the secondary depression and trough were almost identical to the Trial run. Of note, however, is that the thickness analysis showed an amplification of the thermal ridge associated with the easternmost trough by about one degree of latitude in the Control run. This was in the area of the single thickness bogus observation inserted at 0000 GMT.

Despite showing virtually no differences in the 0000 GMT MSLP analysis of the easternmost trough, as the forecast progressed the feature was picked up again and intensified by the Control run more than the Trial run as it crossed the country in the form of a shallow wave. Isobarically, the differences were still fairly modest, but there was a significant increase in the rainfall forecast by the Control run firstly over southern and western Ireland at T+24 (see Figs.5(a) and 5(b)) and later over northern England and Scotland at T+30 (see Figs.5(c) and 5(d)). Verifying against observations at these times show that, in fact, there was very little rain over Ireland at 0000 GMT (Fig.5(e)) and almost none in the area of interest at 0600 GMT (Fig.5(f)). Inspection of the MSLP verifying analysis shows that the easternmost trough did not in fact develop at all, but the western trough did and crossed the country during the following 24 hours.

In this case it would appear that the bogus did have the effect desired at the time of insertion; that of developing the eastern trough into a shallow wave which crossed the UK during the forecast period. However, in reality the bogused trough did not develop, but the feature further west did. Hence the bogus data had a clear negative impact on the forecast. Even the Trial forecast overprdicted the rainfall over the areas in question.

A further point to be made from this case is that despite considerable MSLP bogus inserted at 1800 GMT to develop the easternmost trough and apparent success in the 1800 GMT MSLP analysis, the 0000 GMT MSLP analysis appeared to lose the feature. No further MSLP bogus was inserted in the vicinity of the trough at 0000 GMT except in association with a single thickness observation which was inserted in the region of the thermal ridge. This had an impact on the thickness analysis which produced a significant change in the development of the wave and rainfall associated with it in the forecast. This clearly shows that upper-air bogus data can be a vital tool in influencing the development of a trough or wave.

CASE 6 Forecast from DT 0000 GMT 14.02.90

At 1800 GMT 13th February the whole of the UK was under the influence of a strong westerly airflow associated with a complex area of low pressure with centres over Iceland, the Faeroes and Scotland of approximate depth 970mb. In the mid-Atlantic there was a secondary development with two centres of approximate depth 992mb extending from 50N 30W to 40N 45W. By 0000 GMT the depression centred over Scotland had moved into the North Sea and later crossed Germany and Eastern Europe. The northernmost of the two secondary centres was beginning to deepen and move towards the UK. During the forecast period this centre crossed the UK bringing much rain and it eventually merged with the remaining parent centres to the north of Scotland before moving across the North Sea and into the Low Countries bringing the UK into a run of brisk north-westerly winds.

A total of 26 bogus observations were used by the model in the 1800, 2100 and 0000 GMT assimilation cycles. The majority of these were MSLP and surface wind observations at 1800 GMT inserted around the northernmost secondary depression centre with the intention of producing a more distinct circulation. At 2100 and 0000 GMT more MSLP observations were inserted to deepen the depression centre over Scotland and support some ship observations near the centre of the developing depression.

The analyses at 1800 GMT showed minor differences in the MSLP pattern. The bogus had produced a closed isobar around the northernmost centre of the secondary depression complex, but the centre remained at 992mb. By 0000 GMT the depression centre which moved from Scotland into the North Sea was 1mb deeper in the Control analysis, but positionally the same as the Trial run. However, the secondary centre was both 1mb deeper and positionally some 2 degrees further east in the Control analysis.

Despite being 1mb deeper in the Control analysis, by T+24, when the depression was positioned over Central England and Wales, the Trial forecast had a centre some 2mb deeper at 982mb. At this stage the Control forecast was better since it featured a weaker centre of 984mb and lighter winds due to the lack of an extra isobar near the depression centre present in the Trial run. The verifying analysis and observations indicated a weak depression of about 988mb crossing the country with slack winds of 5-10 knots in most parts of England except the far south-west.

By T+36 the depression had moved into the Low Countries and the Control forecast (Fig.6(a)) had a central pressure of 978mb - some 3mb shallower than the Trial forecast (Fig.6(b)). This compares with the verifying analysis centre of 988mb (Fig.6(c)). However, due to a ridge of high pressure which developed in the South-West and not forecast accurately by either the Control or Trial runs, the pressure gradient across the UK was large producing winds of 25-45 knots in Eastern Counties, the southern North Sea and the Low Countries. Since the Trial forecast featured a deeper depression centre (erroneously), its forecast winds were stronger than the Control forecast by 5-10 knots on average and were, in fact, more accurate. Hence it can be concluded that the bogus data produced a better MSLP forecast, but due to forecast inaccuracies elsewhere, the Trial run inadvertantly produced a better surface wind speed field in the latter stages of the forecast.

CASE 7 Forecast from DT 1200 GMT 09.03.90

At 0600 GMT 9th March a depression with a central pressure of 967mb was situated in the North Atlantic 10 degrees east of Newfoundland. The UK was under a west or north-westerly airstream separated from the depression by a weak ridge of high pressure. By 1200 GMT a distinct trough had developed to the north-east of the main depression. An associated frontal system extended to the east and south of this trough. During the early part of the forecast period the warm front crossed the UK producing much rain. The cold front reached Scotland and Northern Ireland by T+36.

A total of 30 bogus observations were inserted at 0600 GMT and 1200 GMT in a complex operation to adjust the thermal structure of the system and redistribute the moisture associated with it. At 0600 GMT 7 bogus thickness observations were inserted to reshape the thermal ridge and 8 bogus relative humidity observations to dry out the backward edge of the warm front and moisten the area around the frontal triple point. More bogus thickness and relative humidity observations were inserted at 1200 GMT for the same purpose in addition to a few supporting MSLP and AIREP observations.

At 0600 GMT the MSLP analysis differences were small; the isobaric troughing along the cold front was slightly sharper in the Control run. The thickness analysis, however, showed considerable adjustment along the cold front in the Control run. Differences between the Control and Trial fields were up to 4dam; increments of up to 12dam were supplied. The relative

humidity bogus at 500mb and 700mb had a large impact in the 0600 GMT analysis. As bogused, the backward edge of the warm front was dried out and the area around the surface trough, to the north-east of the main depression, was moistened considerably. Differences of over 50% were present between the Control and Trial runs; most of the increments supplied were between 40% and 80%.

At 1200 GMT MSLP analysis differences were modest, being concentrated again on the troughing along the cold front. The Control thickness analysis amplified the thermal ridge by up to 2dam more than the Trial run and differences of up to 50% were present between the Control and Trial analyses of 500mb and 700mb relative humidity. 3 AIREP supporting bogus observations were also inserted into the 1200 GMT assimilation cycle and the maximum wind speed analysis shows a significant shift of the jet core in the Atlantic some 2 degrees further west in the Control run. It is likely that the thickness bogus data inserted in the area were mainly responsible for this change as there was only one AIREP supporting bogus observation in the vicinity.

Both maximum wind speed forecasts developed two jets; one to the north and north-west of the UK and one over Poland. By T+24 the Control jet core over Poland was 169knots- some 10knots stronger than the Trial run (see Figs.7(a) and (b)). The verifying observations showed only 120knots in this area, but in reality the two jets merged and a jet core developed over southern Sweden with observations of 180knots. Fig.7(c) shows the maximum wind speed verifying analysis. Hence it could be said that the Control run jet strength was better, but both forecasts positioned the core too far south-east.

During the forecast period the frontal system occluded and a sharp trough developed to the east of the main depression. By T+18 the rainfall pattern was complex and several differences existed between the Control and Trial forecasts (see Figs.7(d) and 7(e)). These were particularly noticeable on the northern edge of the occlusion just north of Scotland, on the cold front just west of Northern Ireland and on the warm front over East Anglia , Kent, parts of France, Holland and Belgium. Fig.7(f) shows a verifying analysis of MSLP and reveals that the trough over northern Scotland was not as marked as in either forecast. The Trial run was the nearer of the two since its trough was weaker than that shown in the Control forecast. The first two regions mentioned above are over sea areas and hence difficult to verify, although by T+24 the bogus data near the cold front had altered the timing of the onset of rain over Northern Ireland to positive effect. Fig.7(g) shows the verifying observations for the third area of rainfall forecast differences. The Control run forecast rain over parts of East Anglia and Kent. The observations show that there was no rain at the time over these areas. The Trial run features more rain in the vicinity of the Cherbourg peninsula than the Control forecast and the observations show drizzle across the peninsula and to the east. The largest differences were over Belgium and the Dutch/German border area. The observations show much rain, heavy in places, which verifies the Trial forecast much more favourably than the Control.

This would appear to be another case of bogus having the desired effect in the analysis, that of drying out the backward edge of the warm front, but producing a poorer forecast since the warm front produced more rain than anticipated when the bogus data were inserted. In contrast, it was found that bogus data inserted near the cold front did have a positive impact on the rainfall forecast at a later verifying time. The total impact of bogus data on the forecast cannot be fully assessed in this case due to

difficulties in verification over sea areas. However, it would appear that its inclusion has produced both positive and negative results in various places throughout the forecast period.

Summary of Overall Bogus Impact

The 7 cases selected for detailed investigation were categorised according to the impact of bogus data in each as follows:-

1. Positive impact :- Cases 1-4
2. Negative impact :- Case 5
3. Variable impact :- Cases 6-7

In almost all cases the impact on the forecasts was small, especially when compared with the magnitude of the forecast errors.

Of the remaining 18 cases not detailed above, the majority exhibited differences in analysis fields as a result of the inclusion of bogus data. Many also showed forecast differences to varying degrees, but each was considered either too small to verify or insignificant to the Forecaster using the model products as guidance.

In nearly all of the 25 cases the bogus data were related to the development or reshaping of low pressure systems, waves, troughs and fronts and their associated upper-air fields. Hence, it is enevitable that the success of the rainfall forecast is an important indicator as to the impact of bogus data. All rainfall accumulation forecasts (in six-hourly periods up to T+36) were verified against observations from a network of land stations over the UK and Europe and the averaged statistics over all 25 cases are shown in Table 1. The statistic used is dependent to a certain degree on the arbitrary limits of the rainfall categories used, but still gives a good indication of forecast success. The main conclusions to be drawn from these statistics are :-

1. Rainfall forecasts for the whole fine-mesh land area are approximately 12% more accurate than those for just the UK area.

2. Averaged over all 25 cases, bogus data had a small positive impact on the rainfall forecasts.

3. Forecasts for the 6-hour period up to T+12 were the most accurate of all 6-hour periods.

4. Bogus data had the largest positive impact on 6-hourly rainfall accumulation forecasts in the 6 hours up to T+12.

Assessment of Bogus Data Types

Table 2 shows a breakdown of the totals of bogus data inserted over all 25 cases for individual data types or combinations of types inserted at a single latitude/longitude point. Table 3 shows observation-background (O-B) and observation-analysis (O-A) statistics for the bogus observations used in the 7 cases studied in detail and comparable statistics for other data types. The statistics show that over these cases most of the bogus data had a greater impact on the analysis than comparable observational data types. Data

are said to have been "drawn to" when the RMS O-A statistic is less than the RMS O-B statistic. The impact of each bogus type over all 25 cases is summarised below.

1.Mean Sea-Level Pressure (MSLP)

MSLP bogus (which is converted by the model to surface pressure for use in the model) was the most common form of bogus data used, being included in 65% of all bogus observations inserted, frequently supported by surface wind over sea areas. Over the 25 cases it appears that the success of this type of bogus data was varied, but generally less than 40% of the increments supplied were drawn to in the analysis. The variability of success could be attributed to several factors:-

a) Synoptic situation. MSLP bogus appears to have a far smaller impact on mature or deep depressions than on shallower secondary features at an early stage of development. In Cases 2 and 6 the development of secondary depressions was significantly influenced by MSLP bogus inserted during the early stages of cyclogenesis.

b) Bogus structure and technique. In Case 1 a developing depression was deepened and repositioned by bogus data which defined the centre and two surrounding isobars in three successive assimilation cycles. The impact in the analysis was not large, but amplified to produce a greatly improved forecast. In contrast, the bogus data inserted in Case 4 were less well structured, implied pressure gradients beyond the model's resolution and were not greatly supported in subsequent assimilation cycles by further bogus data. The resulting MSLP forecast was not greatly improved. In several of the cases other than the seven studied in detail the definition of too fine a structure prevented bogus data being assimilated effectively.

c) Other bogus types. MSLP bogus on its own had little impact on the forecast in many of the 25 cases, but when supported by thickness or relative humidity bogus, for example, produced a restructuring of the upper-air as well as surface fields which significantly influenced the forecast, as in Cases 4, 5 and 7.

2. Upper-Wind

Of all upper-wind bogus data used in the 25 cases the vast majority was in the form of AIREP support at levels near the tropopause; 12% of all bogus were of this type. The use of lower level winds, for example in the global model around tropical cyclones, cannot, therefore, be assessed by this investigation. Over all the cases it was found that generally less than 30% of the increments from bogus data supporting AIREPs were drawn to in the analysis. However, most increments supplied were very large producing noticeable changes in jet strength on most occasions. Despite these noticeable changes in the analysis, on the whole these differences were rapidly lost in the forecast. On one occasion an analysis difference of 24 knots was reduced to 2 knots by T+24. Of the seven cases studied in detail two showed differences in maximum wind speed fields during the forecast (Cases 2 and 7), but in neither case did the bogus data have a clear positive impact. Hence, over this sample of cases, bogus data have not contributed greatly to the forecast of upper-winds.

3. Relative Humidity

Relative humidity bogus data were inserted into 9 of the 25 Trial cases (a total of 18% of all data inserted) and in 3 of the 7 examined in detail. Of these 3 (Cases 3, 4 and 7) relative humidity bogus data had a significant impact on the forecast by moistening or drying out frontal zones or waves producing verifiable changes to the rainfall forecast over the UK and Europe. It is noticeable that in these three cases the bogus data were either at multiple levels (e.g. 850, 700 and 500mb) or had large positive or negative increments (greater than 50%) or both. Of the remaining six cases of relative humidity bogus not detailed above some were successful in changing the rainfall forecast, but these changes were not verifiable since they were over sea areas. The other cases were not so successful and a common factor in each was that bogus data were inserted at just one level or with fairly modest positive or negative increments which would appear to restrict the impact on rainfall forecasts. Of all bogus data types the model analysis responded most favourably to relative humidity assimilating more than 50% of increments supplied on many occasions.

4. Thickness and Height

Thickness (invariably 500-1000mb) or height bogus data were inserted in 12 of the 25 cases, 5 of which were from the 7 studied in detail; this amounts to a total of 9% of all bogus data inserted. On the whole, the impact was found to be variable, but good in the latter cases (Cases 2, 3, 4, 5 and 7). On the majority of occasions thickness bogus were inserted to reposition a frontal zone or amplify a thermal ridge near a developing wave. Generally, it was found that less than 40% of thickness increments were drawn to in the analysis, but the impact was usually maintained well into the forecast.

A single, critically positioned bogus observation had a large impact on the forecast in Case 5, but generally the greatest degree of success was experienced by the systematic repositioning of a chosen contour by thickness bogus data as in Cases 3 and 7. In these cases, the combination of thickness and relative humidity bogus had a large impact on the timing of and rainfall amounts associated with frontal systems.

CONCLUSIONS

Examination of the random sample of 25 cases has shown that the success of bogus data is clearly dependent on a large number of factors; these include the assimilation techniques employed by the fine-mesh model, data quality control, the types and combinations of data as well as their structure and the increments supplied. Hence, the variation in impact from nil or negative, to a clear positive impact is to be expected considering the number of factors involved.

This investigation has shown that from a sample of 25 cases the impact of bogus data increments on the analysis was generally less than 50% of that which was desired. Relative humidity bogus has the greatest impact. It has also been shown how the fine-mesh model assimilates bogus data under a variety of different conditions; statistics from 7 of these cases show that generally bogus data had a greater impact on the analysis than comparable observational data types. These 7 cases were found to produce forecast differences as a result of the inclusion of bogus data which would probably have altered the way in which the model guidance was interpreted. The differences between the Trial and Control runs were nevertheless small.

A full evaluation of bogus data can only be made by examining their impact in the global model over a large number of cases. In this instance 25 cases were examined using the fine-mesh model. However, it is intended that these limited results should inform and assist in the effective and economical use of bogus data in the future.

6-Hourly Rainfall Accumulation Forecast Verification Averaged over all 25 Cases

Percentage of forecasts in the correct category
Categories :- nil, 0.1-1.9mm, 2.0-9.9mm, 10.0mm+

6-hour period up to forecast time	UK LAND AREA			WHOLE FINE-MESH LAND AREA		
	CONTROL	TRIAL	CONTROL -TRIAL	CONTROL	TRIAL	CONTROL -TRIAL
T+6	61.19	60.09	+1.10	74.64	74.40	+0.24
T+12	62.93	61.23	+1.70	75.78	75.42	+0.31
T+18	62.04	60.93	+1.11	73.50	73.42	+0.08
T+24	62.17	62.10	+0.07	71.19	71.26	-0.07
T+30	61.97	62.63	-0.66	72.25	72.16	+0.09
T+36	61.98	62.88	-0.90	72.84	72.99	-0.15
All Forecast Periods	62.05	61.63	+0.42	73.36	73.30	+0.06

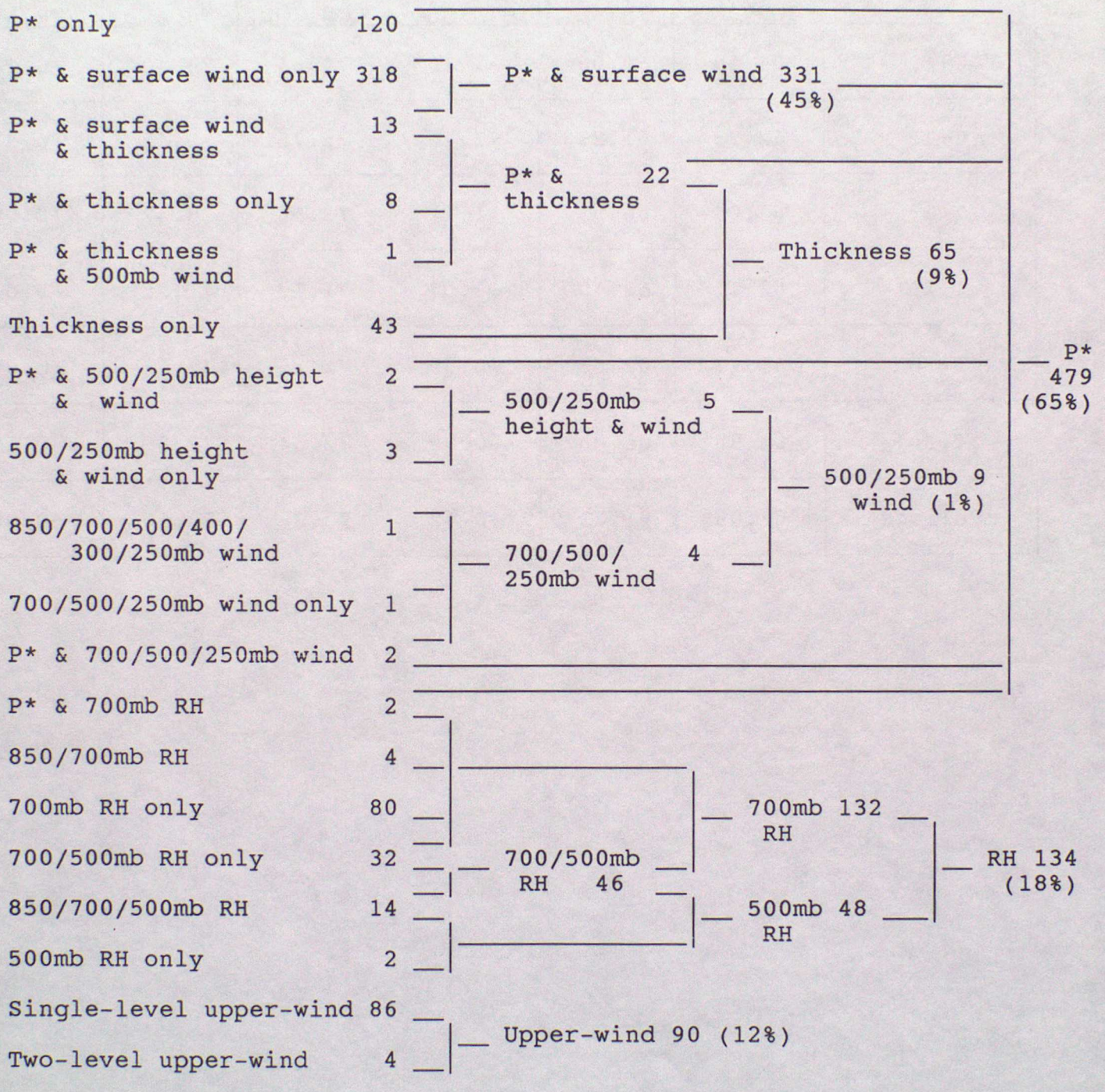
TABLE 1

A Breakdown of Bogus Observation Totals for all 25 Cases

All data inserted at a particular latitude/longitude point is considered to be a single bogus observation.

P* = Surface pressure
RH = Relative humidity

Some percentages of the total bogus effort are shown


P* only 120
P* & surface wind only 318
P* & surface wind & thickness 13
P* & thickness only 8
P* & thickness & 500mb wind 1
Thickness only 43
P* & 500/250mb height & wind 2
500/250mb height & wind only 3
850/700/500/400/ 300/250mb wind 1
700/500/250mb wind only 1
P* & 700/500/250mb wind 2
P* & 700mb RH 2
850/700mb RH 4
700mb RH only 80
700/500mb RH only 32
850/700/500mb RH 14
500mb RH only 2
Single-level upper-wind 86
Two-level upper-wind 4
P* & surface wind 331 (45%)
P* & thickness 22
Thickness 65 (9%)
500/250mb height & wind 5
500/250mb wind 9 (1%)
700/500/ 250mb wind 4
P* 479 (65%)
700/500mb RH 46
700mb 132 RH
500mb 48 RH
RH 134 (18%)
Upper-wind 90 (12%)

TOTAL NUMBER OF BOGUS OBSERVATIONS INSERTED IN ALL 25 CASES :- 736

TABLE 2

Statistics for Bogus Data and Other Data Types

RMS O-B = Root-mean-square observation-background

RMS O-A = Root-mean square observation-analysis

$$\% \text{ Drawn to} = \frac{(\text{RMS O-B}) - (\text{RMS O-A})}{\text{RMS O-B}} \times 100\%$$

	BOGUS DATA (see NOTES)			OTHER DATA TYPES (See NOTES)		
	RMS O-B	RMS O-A	% Drawn to	RMS O-B	RMS O-A	% Drawn to
Surface pressure (mb)	3.2	2.2	30.1	1.8	1.3	27.8
Surface wind speed (knots)	13.4	10.6	20.9	8.1	6.2	23.5
Surface wind direction (deg)	50.4	38.9	22.8	31.0	22.0	29.0
Rel. humidity 850mb (%)	31.8	12.8	59.7	24.2	13.4	44.6
Rel. humidity 700mb (%)	39.2	14.3	63.5	25.4	13.6	46.5
Rel. humidity 500mb (%)	49.7	21.2	57.3	32.7	17.4	46.8
Temperature 950-500mb (K)	2.5	1.5	40.0	1.5	0.9	40.0
Wind speed 350-151mb (kn)	37.6	22.5	40.2	13.0	10.2	21.5
Wind direction 350-151mb (deg)	7.8	7.1	9.0	24.0	19.6	18.3

TABLE 3

NOTES on Bogus Data

All statistics are for bogus data averaged over all assimilation cycles relevant to the the seven cases studied in detail above for the fine-mesh area.

NOTES on Other Data Types

All statistics are for unflagged observations listed below averaged over the period 1-31 December 1989 within the fine-mesh area.

Surface Pressure
wind speed and direction : All surface ship observations

Relative humidity : All TEMPSHIP observations for pressure bands :-
850-751mb 750-651mb 550-451mb

Temperature : All TEMPSHIP observations averaged over pressure band
950-451mb

Wind speed and direction (350-151mb) : All AIREPS

Summary of Figures

All figures relate to the fine-mesh model; "Control" indicates a rerun with all observations, "Trial" indicates a rerun without bogus data.

Figure 1(a) : Control T+24 forecast. DT 1200 GMT 17.08.89

(b) : Trial T+24 forecast. DT 1200 GMT 17.08.89

(c) : Verifying analysis. DT 1200 GMT 18.08.89

Figure 2(a) : Control T+36 forecast. DT 1200 GMT 11.12.89

(b) : Trial T+36 forecast. DT 1200 GMT 11.12.89

(c) : Verifying observations. DT 0000 GMT 13.12.89

(d) : Verifying observations. DT 0300 GMT 13.12.89

Figure 3(a) : Control T+12 forecast. DT 1200 GMT 24.12.89

(b) : Trial T+12 forecast. DT 1200 GMT 24.12.89

(c) : Verifying observations. DT 0000 GMT 25.12.89

(d) : Verifying observations. DT 0300 GMT 25.12.89

Figure 4(a) : Control T+18 forecast. DT 0000 GMT 06.02.90

(b) : Trial T+18 forecast. DT 0000 GMT 06.02.90

(c) : Verifying analysis. DT 1800 GMT 06.02.90

(d) : Verifying observations. DT 1500 GMT 06.02.90

(e) : Verifying observations. DT 1800 GMT 06.02.90

Figure 5(a) : Control T+24 forecast. DT 0000 GMT 08.02.90

(b) : Trial T+24 forecast. DT 0000 GMT 08.02.90

(c) : Control T+30 forecast. DT 0000 GMT 08.02.90

(d) : Trial T+30 forecast. DT 0000 GMT 08.02.90

(e) : Verifying observations. DT 0000 GMT 09.02.90

(f) : Verifying observations. DT 0600 GMT 09.02.90

Figure 6(a) : Control T+36 forecast. DT 0000 GMT 14.02.90

(b) : Trial T+36 forecast. DT 0000 GMT 14.02.90

(c) : Verifying analysis. DT 1200 GMT 15.02.90

(d) : Observations. DT 1200 GMT 15.02.90

Figure 7(a) : Control T+24 forecast. DT 1200 GMT 09.03.90

(b) : Trial T+24 forecast. DT 1200 GMT 09.03.90

(c) : Verifying analysis. DT 1200 GMT 10.03.90

(d) : Control T+18 forecast. DT 1200 GMT 09.03.90

(e) : Trial T+18 forecast. DT 1200 GMT 09.03.90

(f) : Verifying analysis. DT 0600 GMT 10.03.90

(g) : Verifying observations. DT 0600 GMT 10.03.90

DT 12Z THUR 17/ 8/89 VT 12Z FRI 18/ 8/89 MAIN T+ 24

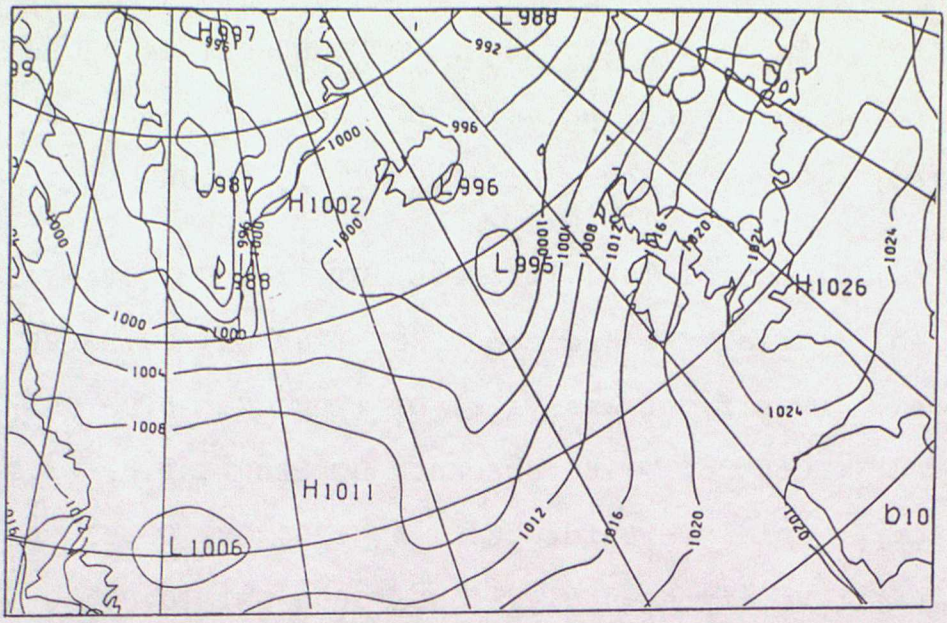


FIGURE 1(a)

CONTROL

DT 12Z THUR 17/ 8/89 VT 12Z FRI 18/ 8/89 MAIN T+ 24

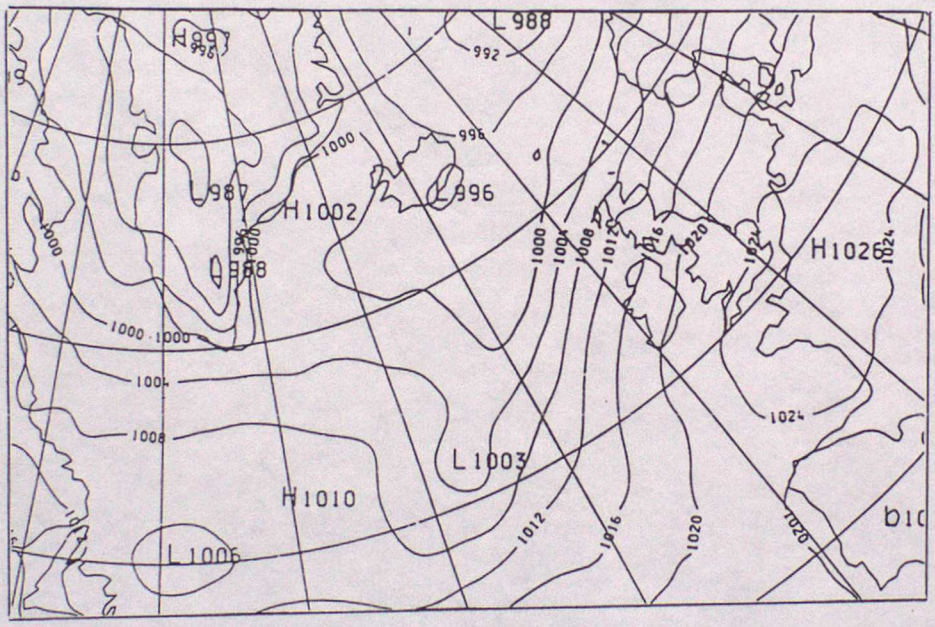


FIGURE 1(b)

TRIAL

DT 12Z FRI 18/ 8/89 VT 12Z FRI 18/ 8/89 MAIN T+ 0

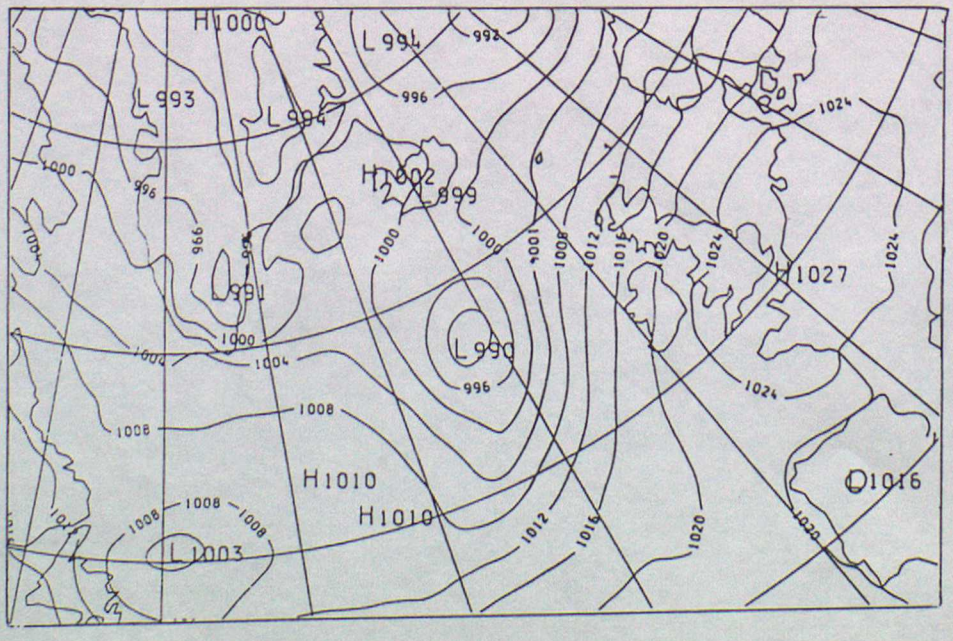


FIGURE 1(c)

VERIFYING

ANALYSIS

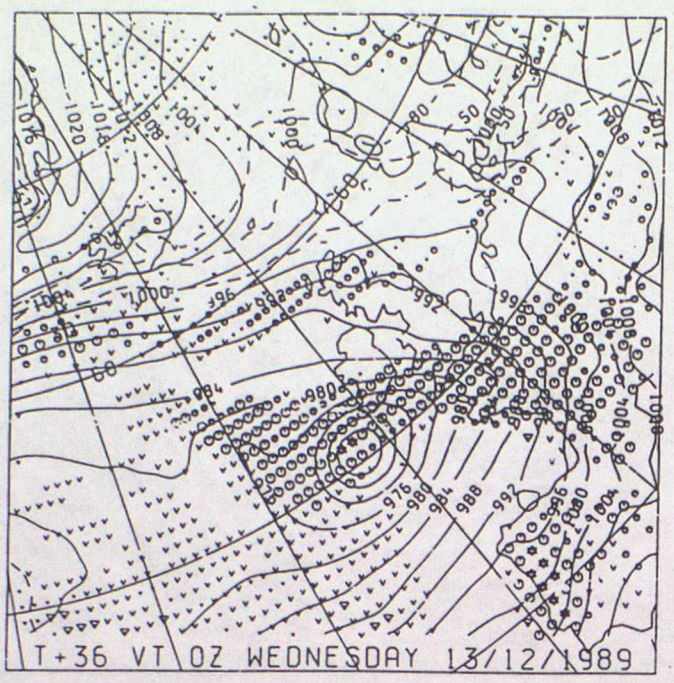


FIGURE 2(a) CONTROL

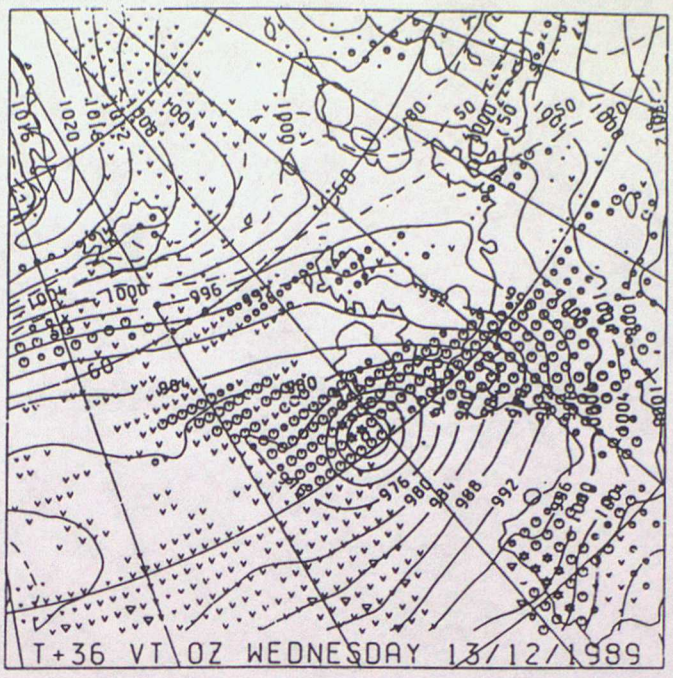


FIGURE 2(b) TRIAL

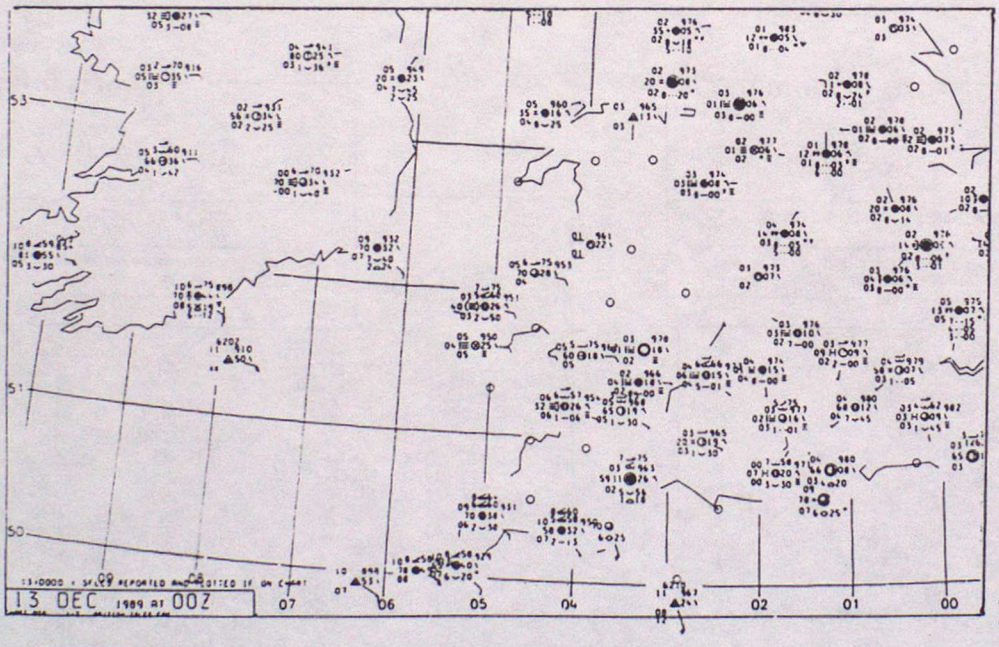


FIGURE 2(c)

VERIFYING OBSERVATIONS

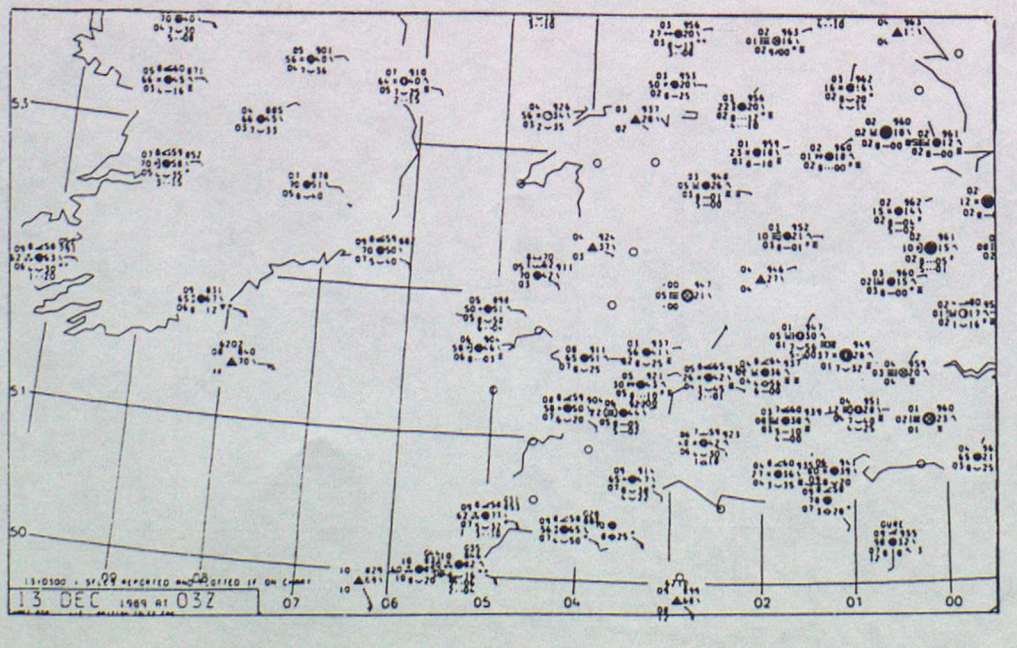


FIGURE 2(d)

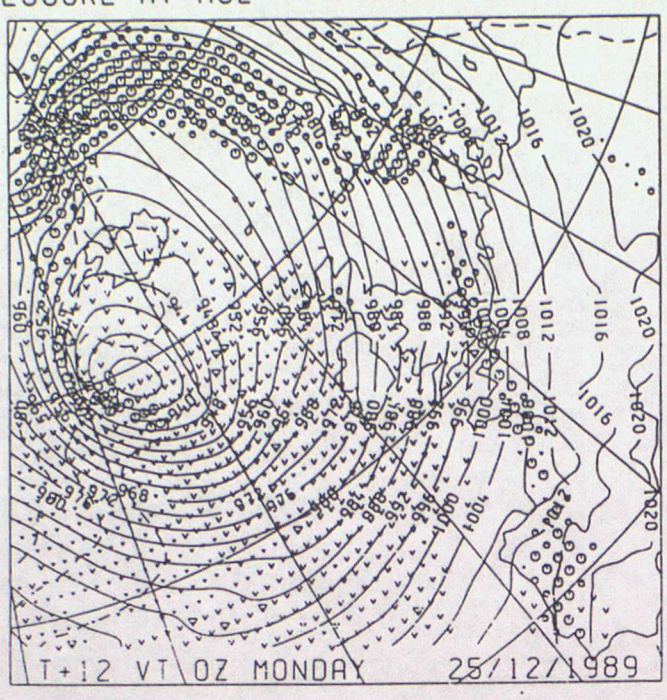


FIGURE 3(a) CONTROL

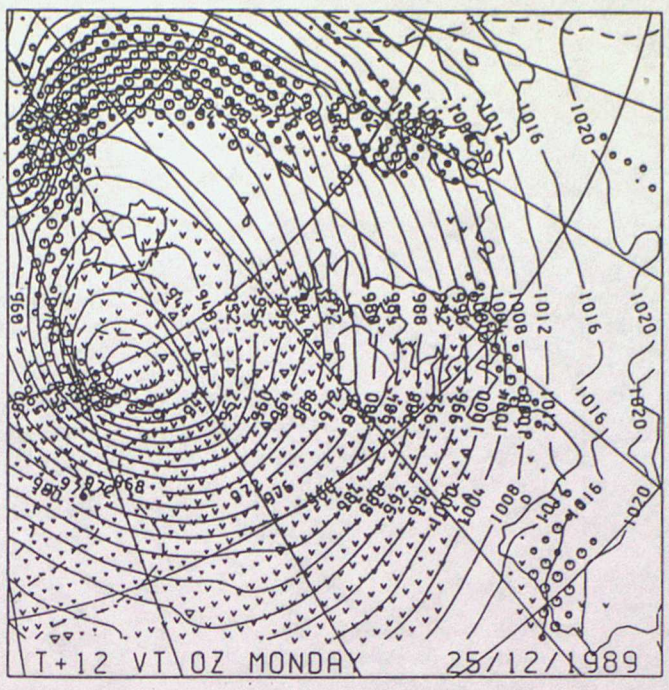


FIGURE 3(b) TRIAL

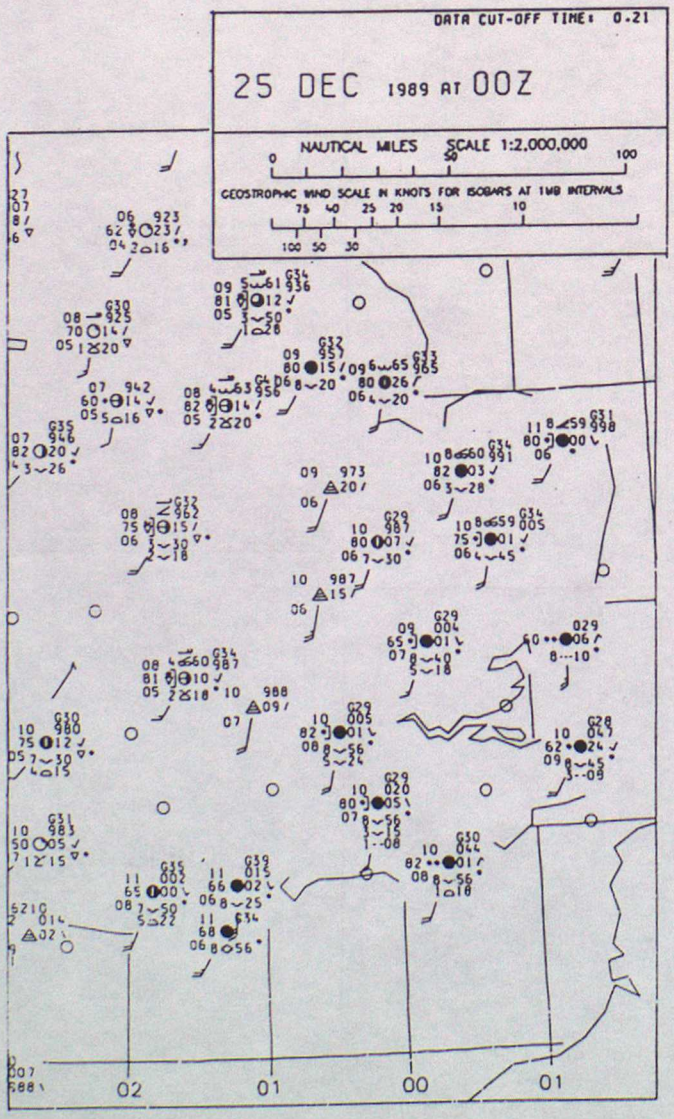


FIGURE 3(c)

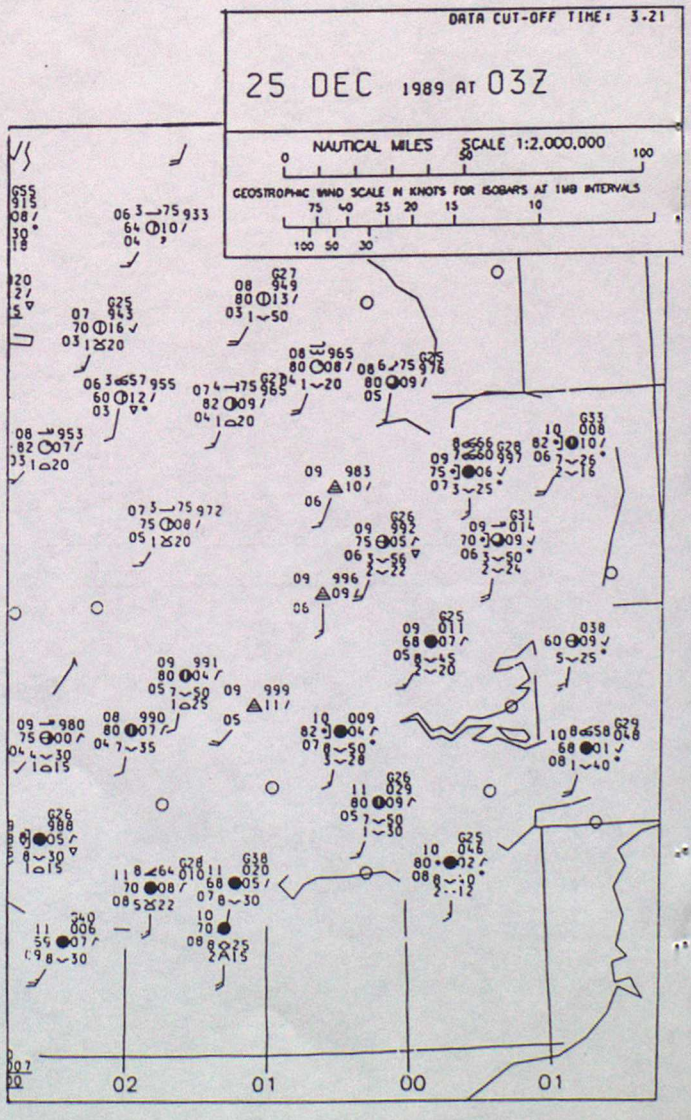


FIGURE 3(d)

VERIFYING OBSERVATIONS

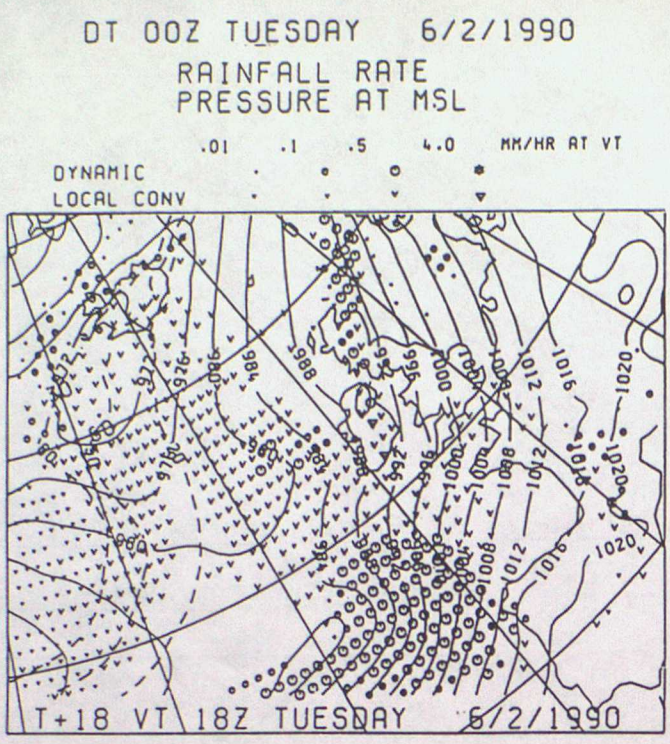


FIGURE 4(a) CONTROL

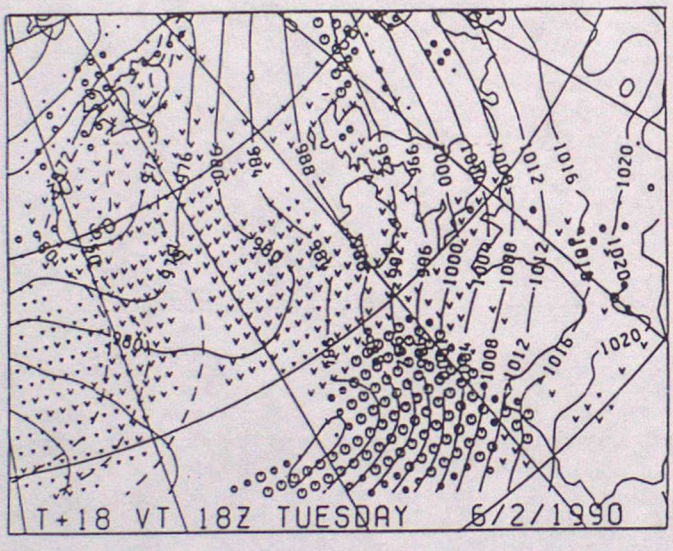


FIGURE 4(b) TRIAL

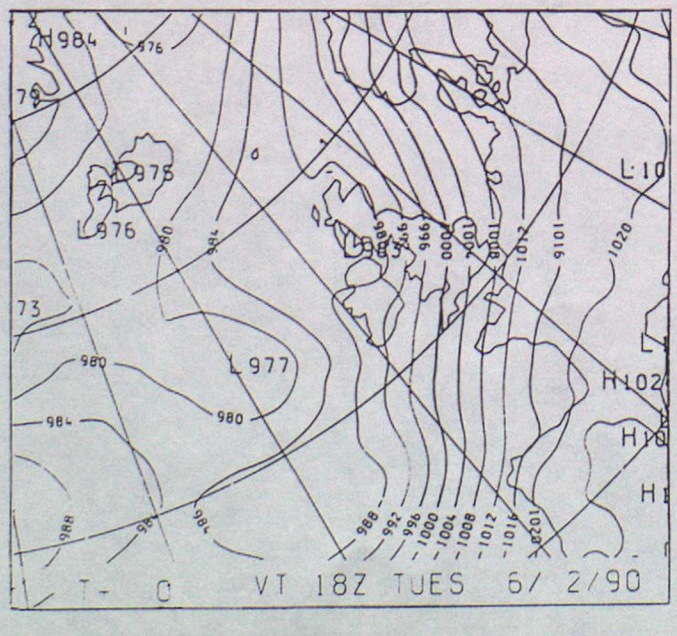


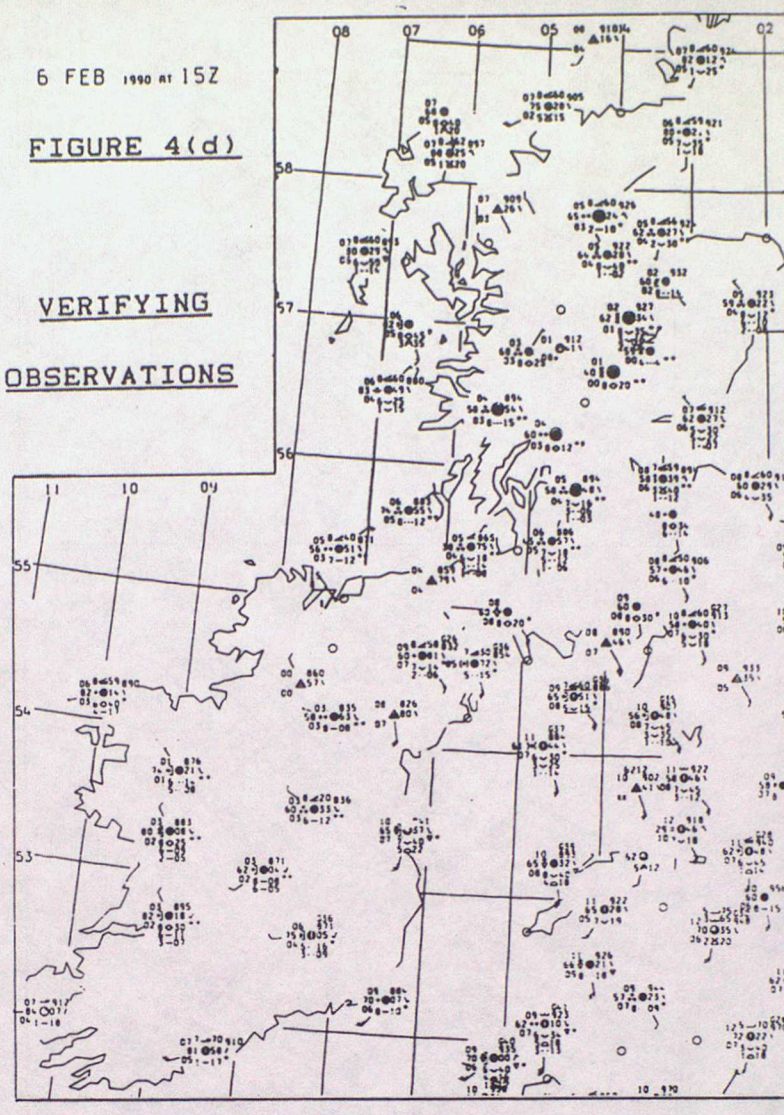
FIGURE 4(c) VERIFYING ANALYSIS

6 FEB 1990 AT 15Z

FIGURE 4(d)

VERIFYING

OBSERVATIONS

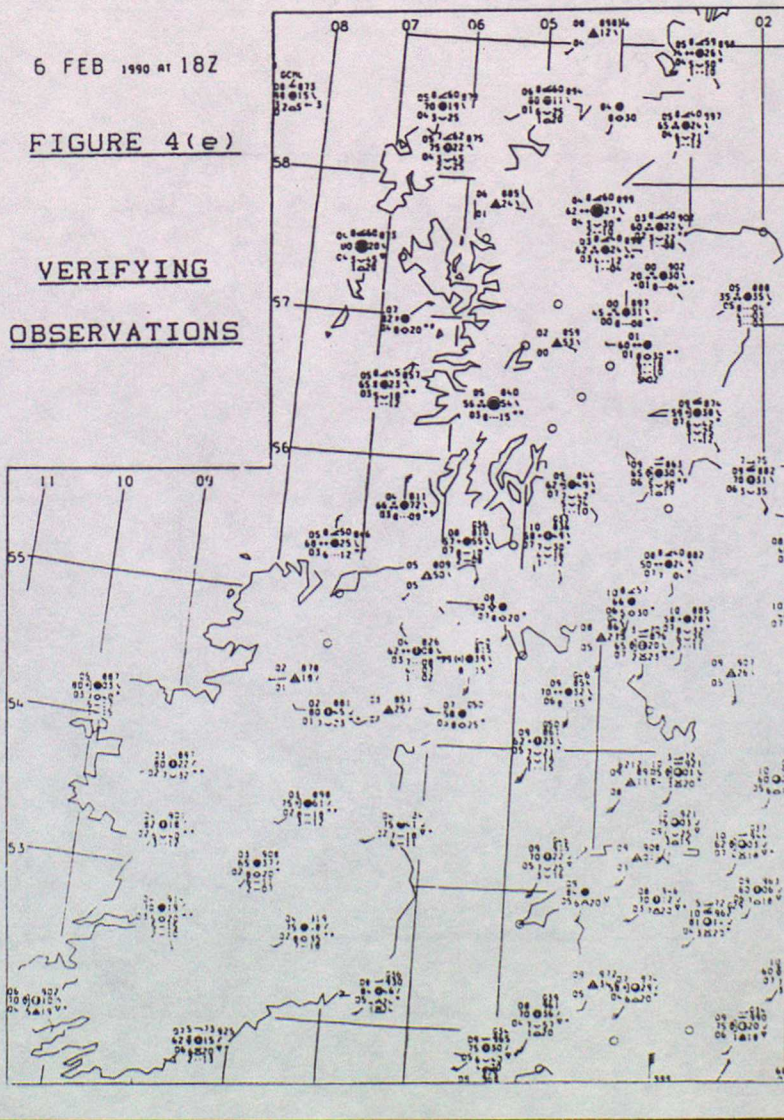


6 FEB 1990 AT 18Z

FIGURE 4(e)

VERIFYING

OBSERVATIONS



DT 00Z THURSDAY 8/2/1990

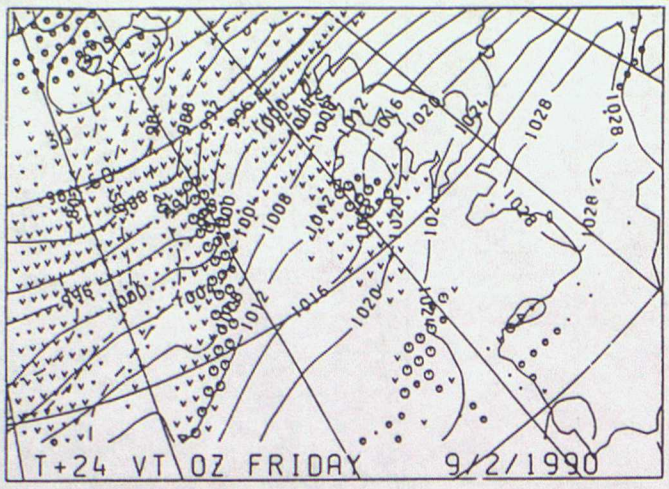
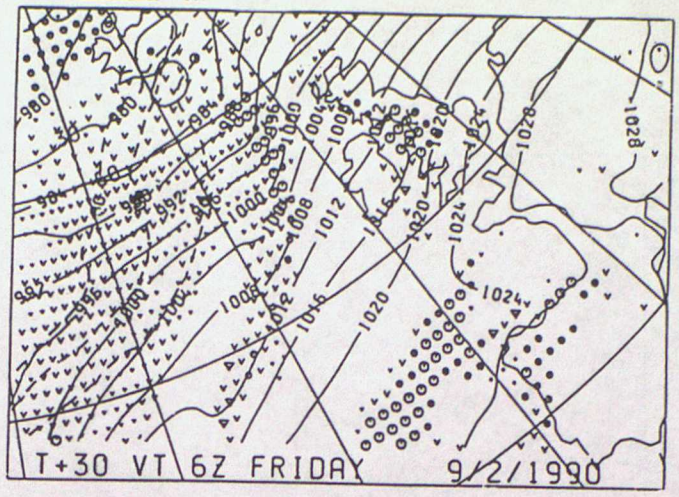


FIGURE 5(a) CONTROL



CONTROL FIGURE 5(c)

RAINFALL RATE
PRESSURE AT MSL

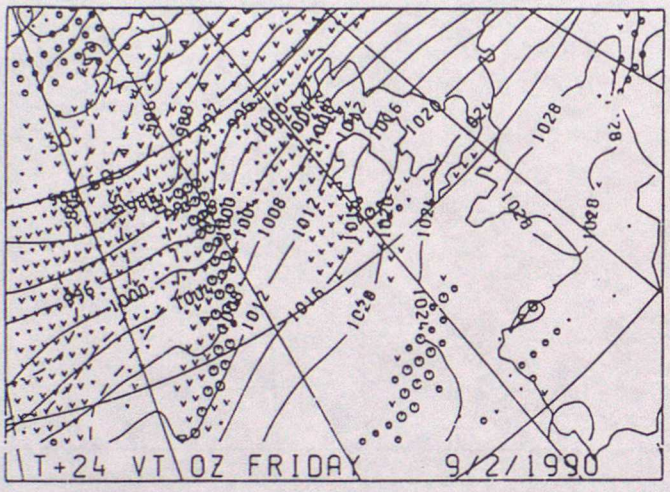
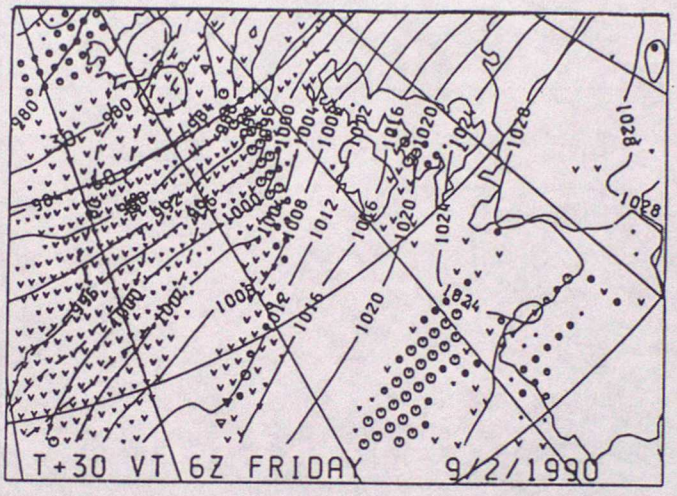
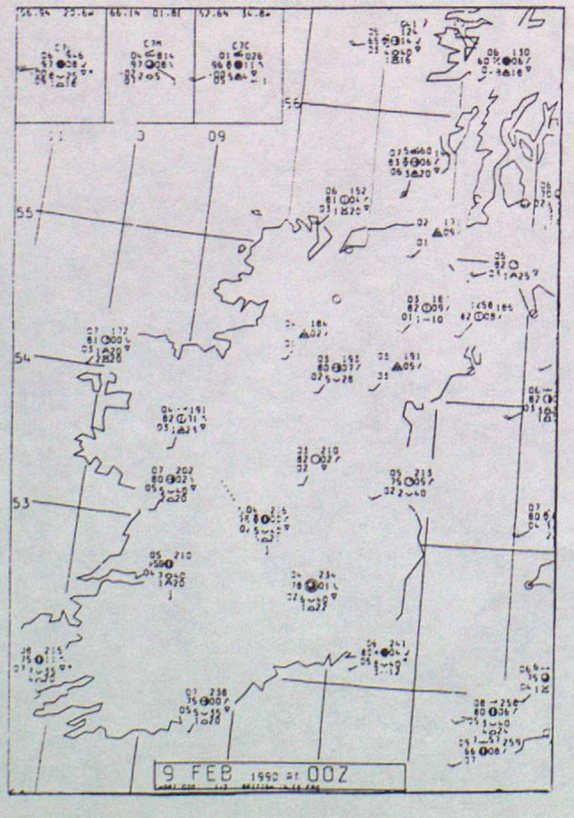


FIGURE 5(b) TRIAL



TRIAL FIGURE 5(d)



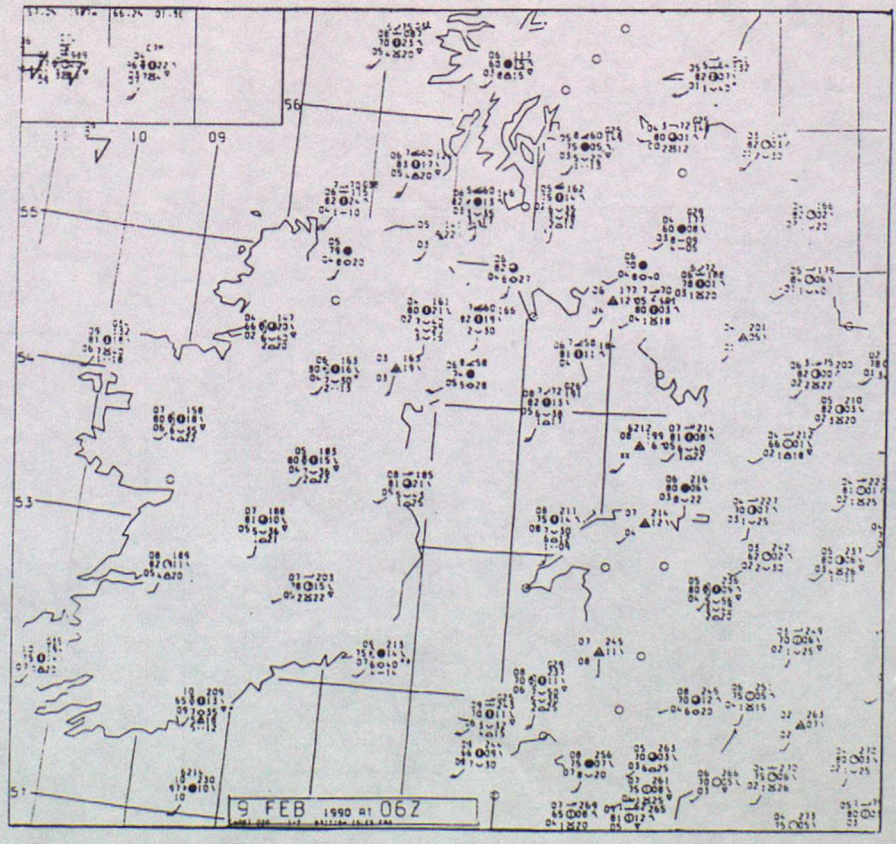


FIGURE 5(e) VERIFYING OBSERVATIONS FIGURE 5(f)

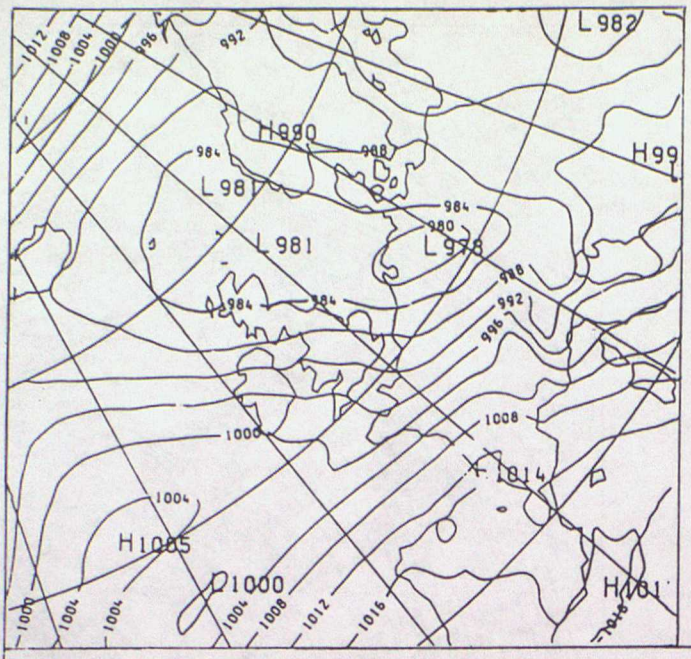


FIGURE 6(a)

CONTROL

DT 00Z WED 14/ 2/90 VT 12Z THUR 15/ 2/90 T+ 36

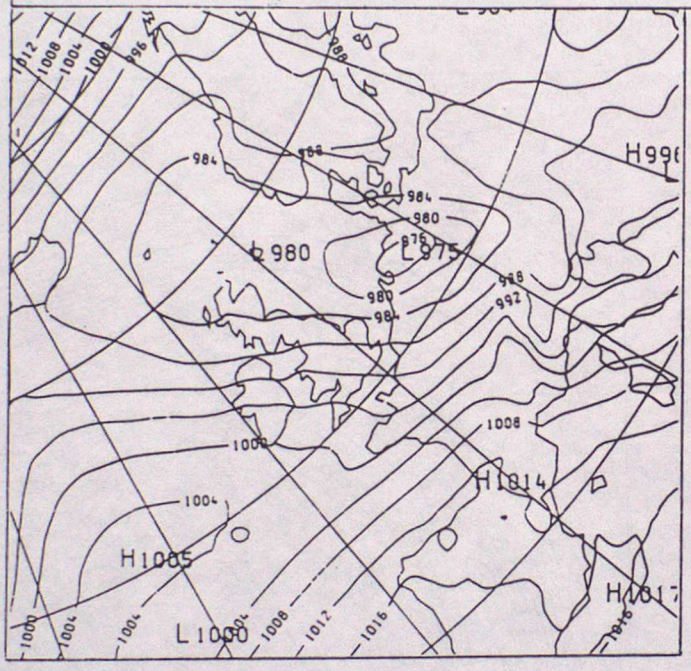


FIGURE 6(b)

TRIAL

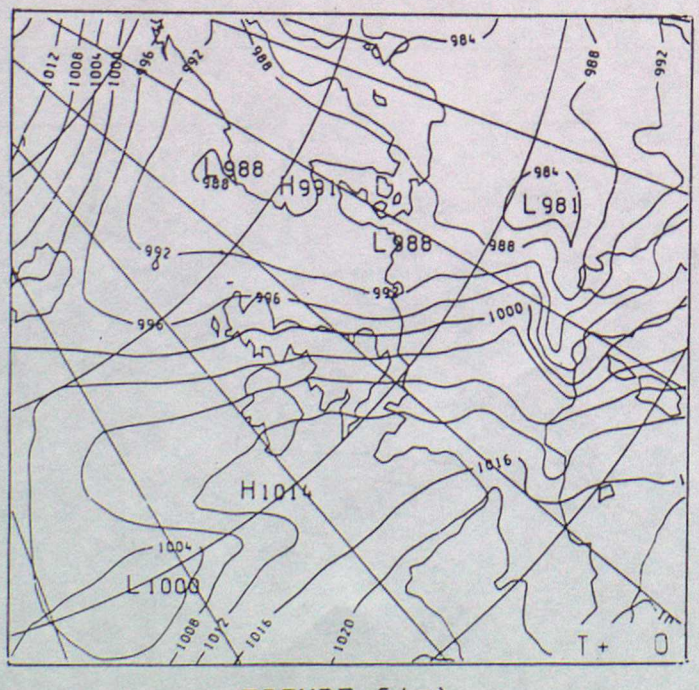


FIGURE 6(c)

VERIFYING ANALYSIS

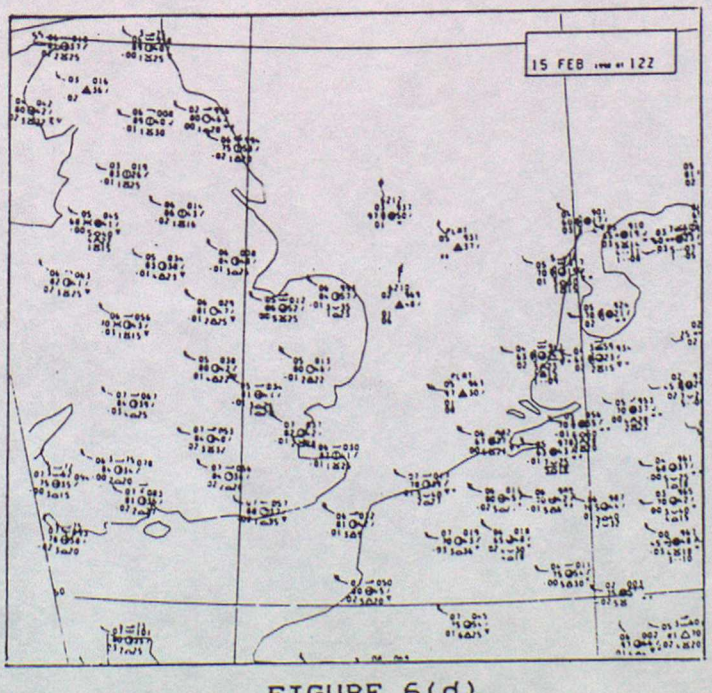


FIGURE 6(d)

OBSERVATIONS

MAX WIND SPEED KT.

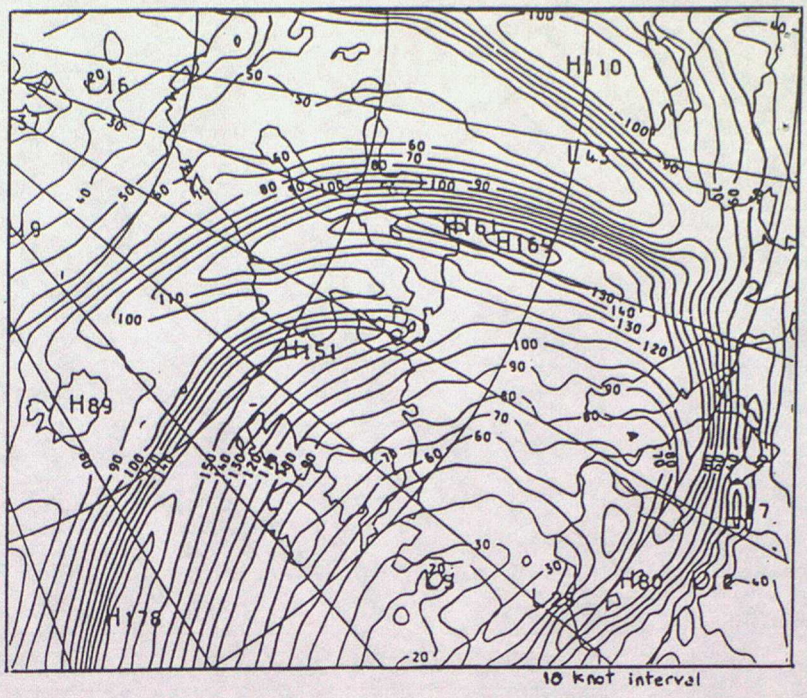
DT 12Z FRI 9/ 3/90

VT 12Z SAT 10/ 3/90

MAIN T+ 24

CONTROL

FIGURE 7(a)



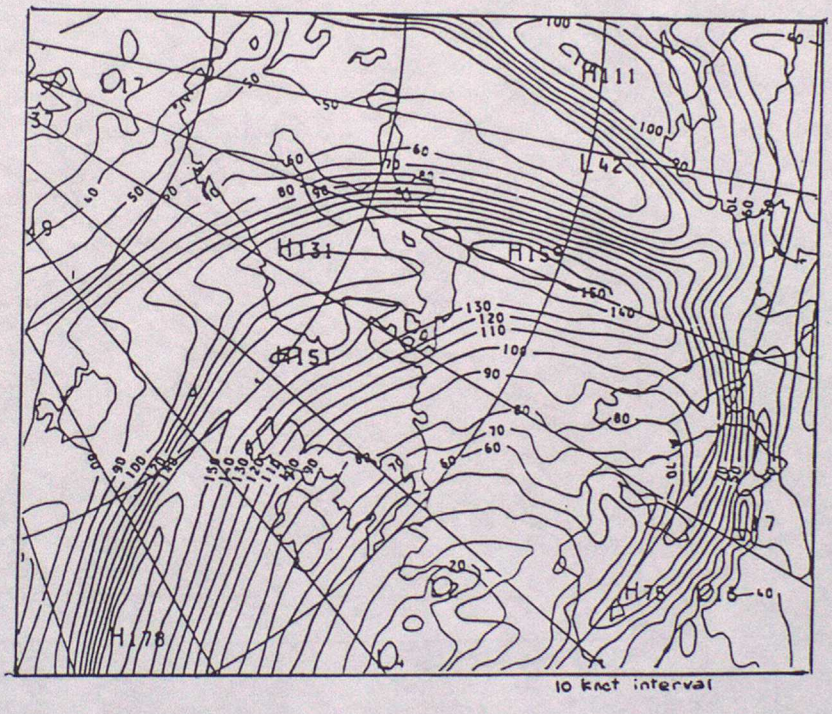
DT 12Z FRI 9/ 3/90

VT 12Z SAT 10/ 3/90

MAIN T+ 24

TRIAL

FIGURE 7(b)

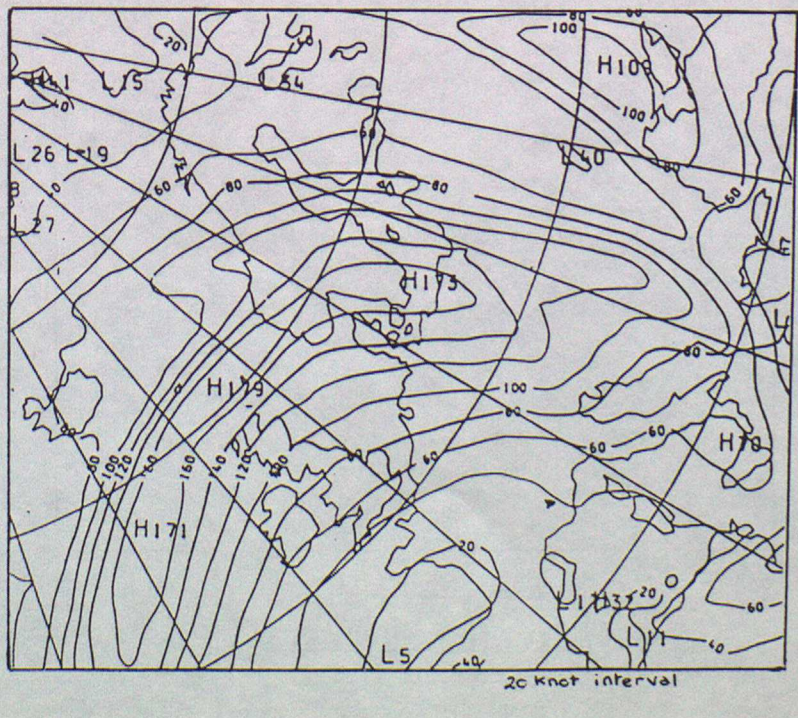


DT 12Z SAT 10/ 3/90

MAIN T+ 0

VERIFYING ANALYSIS

FIGURE 7(c)



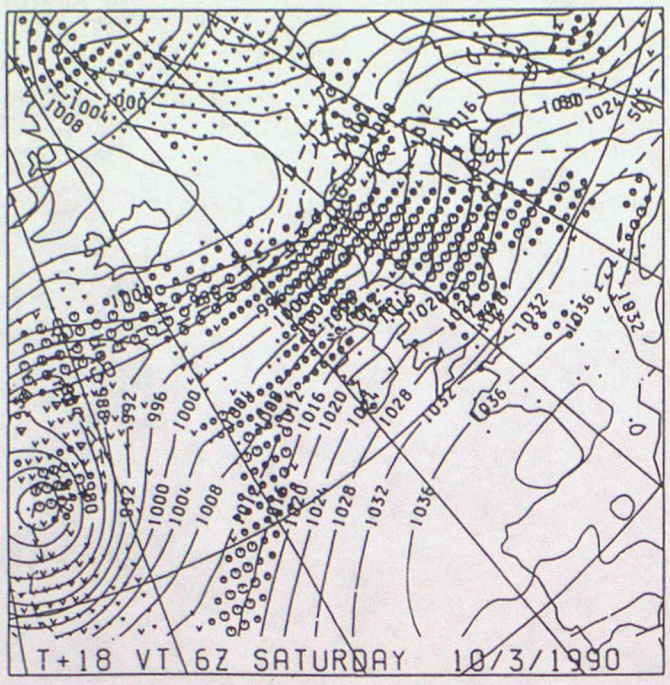


FIGURE 7(d) CONTROL

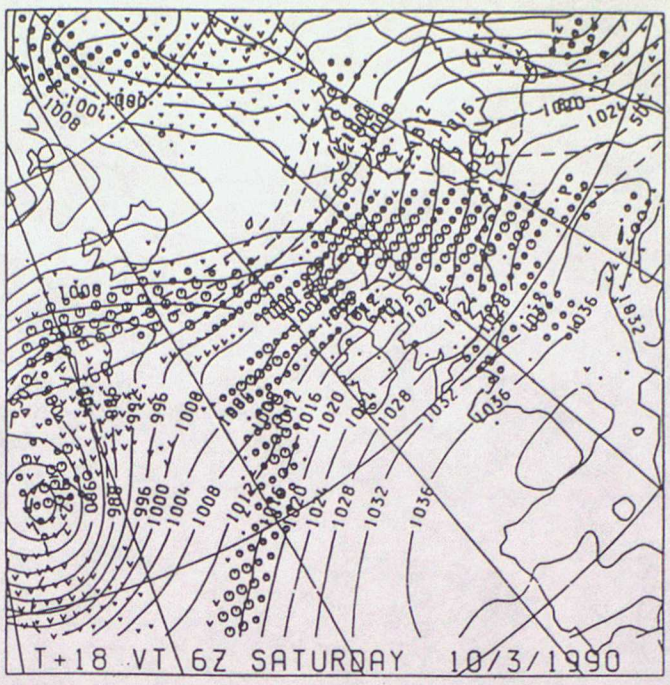
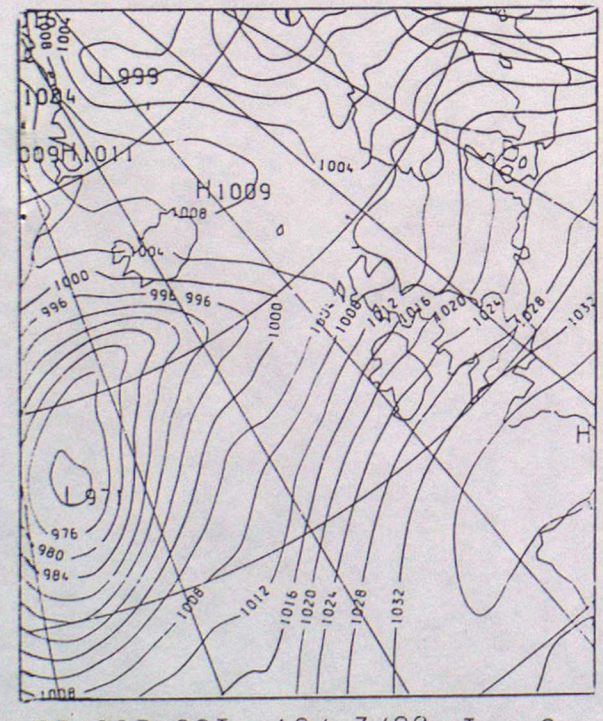
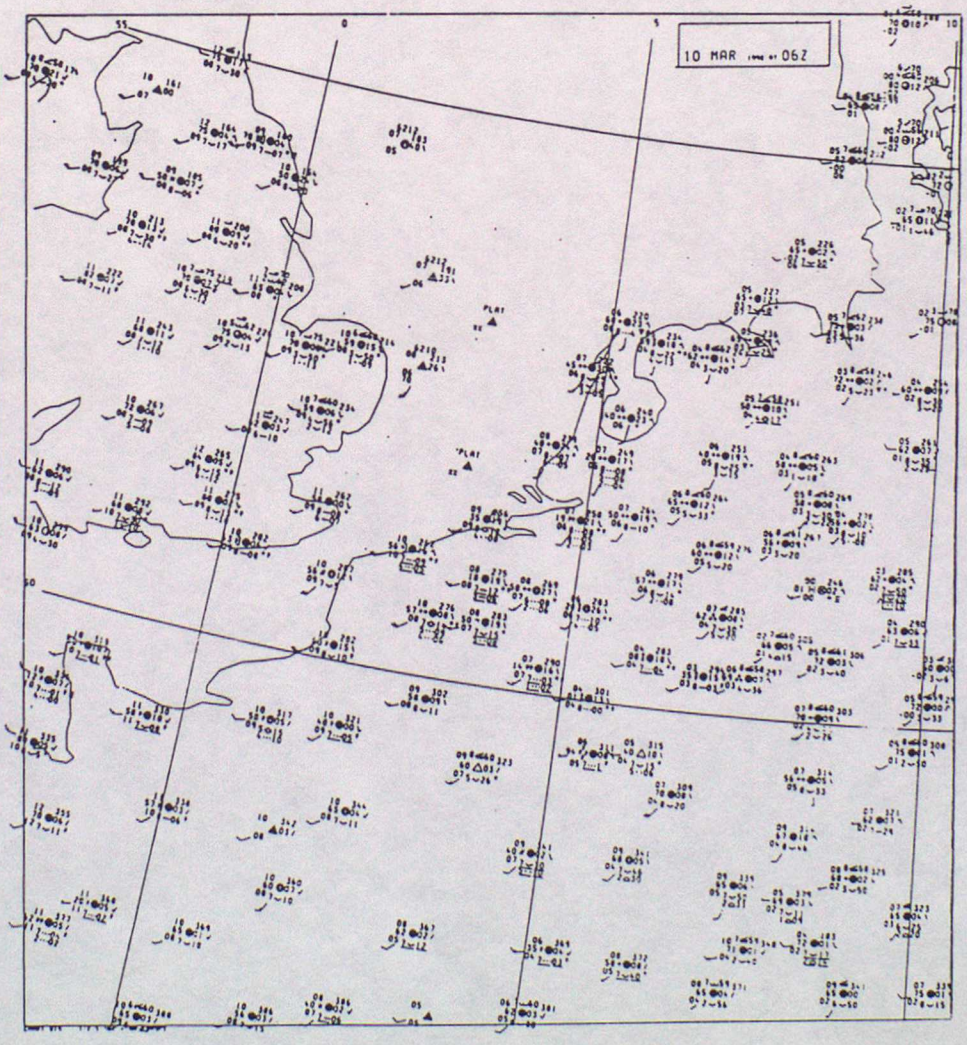


FIGURE 7(e) TRIAL



VERIFYING ANALYSIS

FIGURE 7(f)



VERIFYING OBSERVATIONS

FIGURE 7(g)